SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN-MADISON

Leveraging Artificial Intelligence (AI) to Improve Current Asphalt Mixture Design, Pavement Monitoring, and Maintenance Decisions

WAPA's 66th Annual Conference

12/02/2025

Runhua Zhang, Hussain Bahia; Xiaopeng (Shaw) Li; Sikai (Sky) Chen

University of Wisconsin-Madison

WAPA WISCONSIN ASPHALT PAVEMENT ASSOCIATION

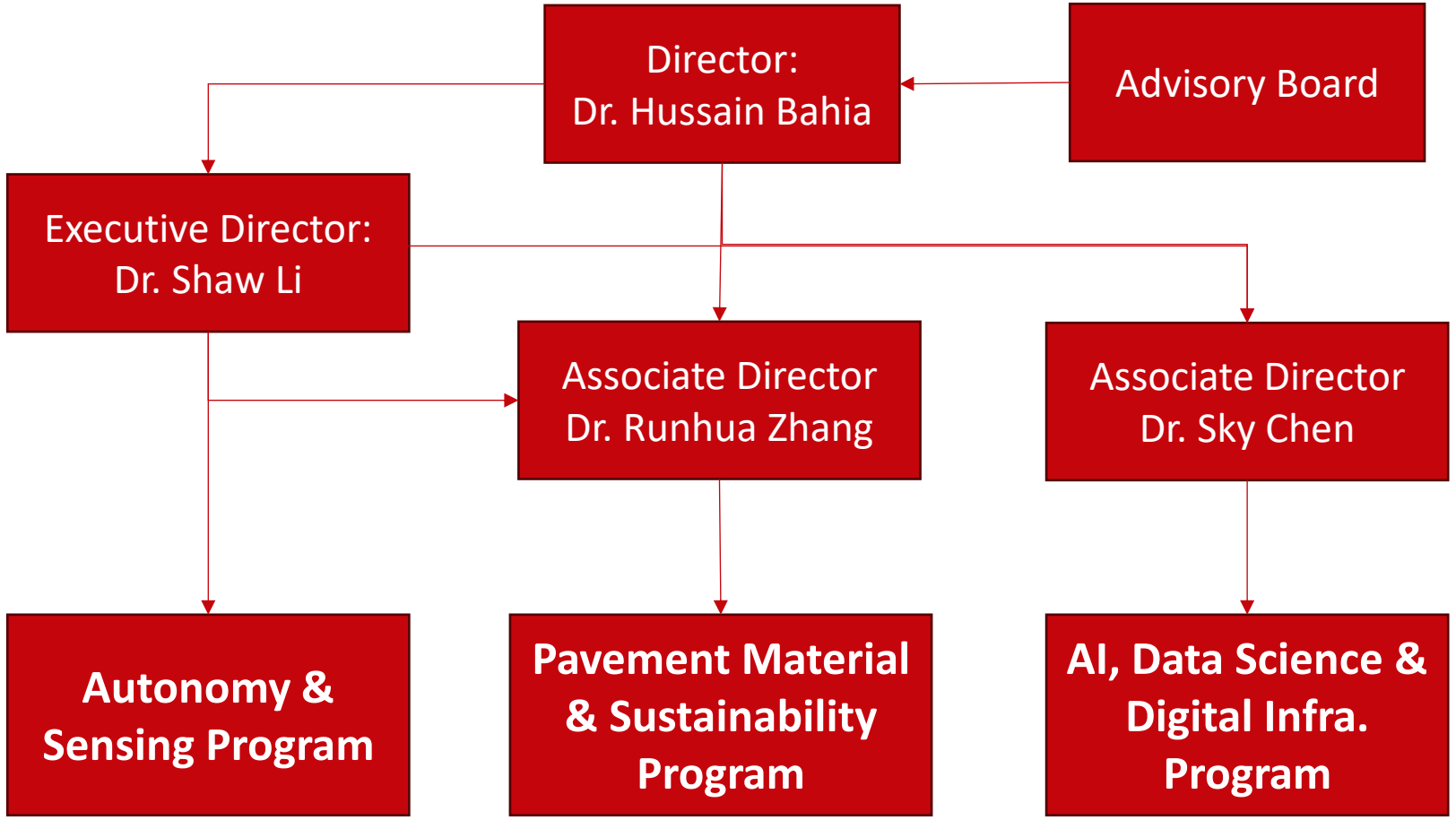
Smart Highway Research Center (SHRC)

MARC MODIFIED ASPHALT RESEARCH CENTER

Established in 2009

SHRC SMART HIGHWAY RESEARCH CENTER

Expanded in 2025



Postdoc.; Graduate Students; Visiting Scholars

SHRC Current Research Focus

- **Use of AI / Sensing / Automation Technology in Pavement Engineering**
  - **Development of Integrated Road Project Information System (IRIS)**
  - **Low-cost Pavement Condition Evaluation**
  - **Automated Pavement Maintenance**
  - Automated Quality Management
  - AI Training of Workforce
- **Durable and Sustainable Pavement Solutions**
  - Low-energy / Low-temperature / Low-Cost Mix Design
  - High RAP Mixes and Specialty Rejuvenators
  - Development of the CPR-Index for BMD

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

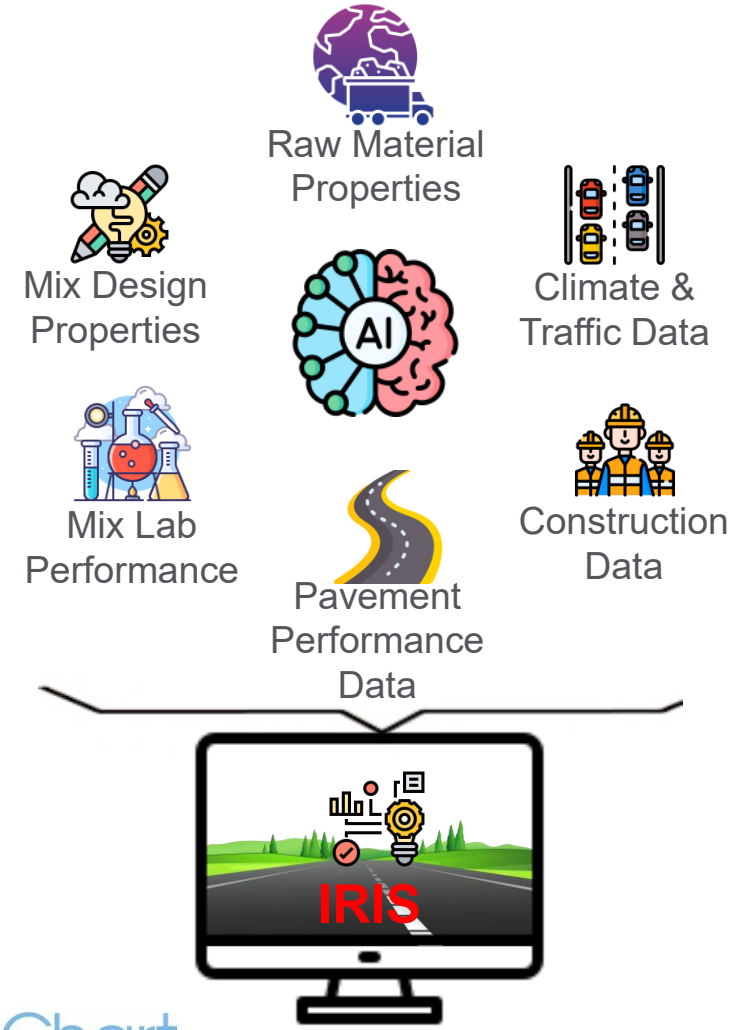
Development of Integrated Road Project Information System (IRIS)

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

IRIS - Integrated Road Project Information System (IRIS)

- **Current Practice:**
  - Materials, mix designs, construction and performance data are not integrated or used intelligently
- **Challenges:**
  - **<u>Pavement delivery and management data is siloed and underutilized</u>**
  - Exponential future growth in data amount and science
- **Solutions:**
  - Integrate, understand, and utilize data using **<u>AI</u>**
  - Develop the ***Road Project Information System (IRIS)***
- **Benefits:**
  - Improve efficiency of mixture design and acceptance (reduce testing)
  - Support decision-making for performance and budget management



SHRC SMART HIGHWAY RESEARCH CENTER

MyChart powered by Epic

WISCONSIN UNIVERSITY OF WISCONSIN-MADISON

IRIS- Current Focus and Progress

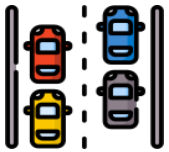
- **To date, we have enough data to work on the mix design phase:**
  - Volumetrics design
  - Performance-based design
    - ✓ Balanced Mix Design
  - Prototype AI tools will be posted on our website
    - ✓ Expected in March 2026
- **We also have ideas for:**
  - Low-cost **monitoring of performance** to start data collection
- **Other phases will be added in the future**

Raw Material Properties

Mix Design Properties

Mix Lab Performance

Construction Data



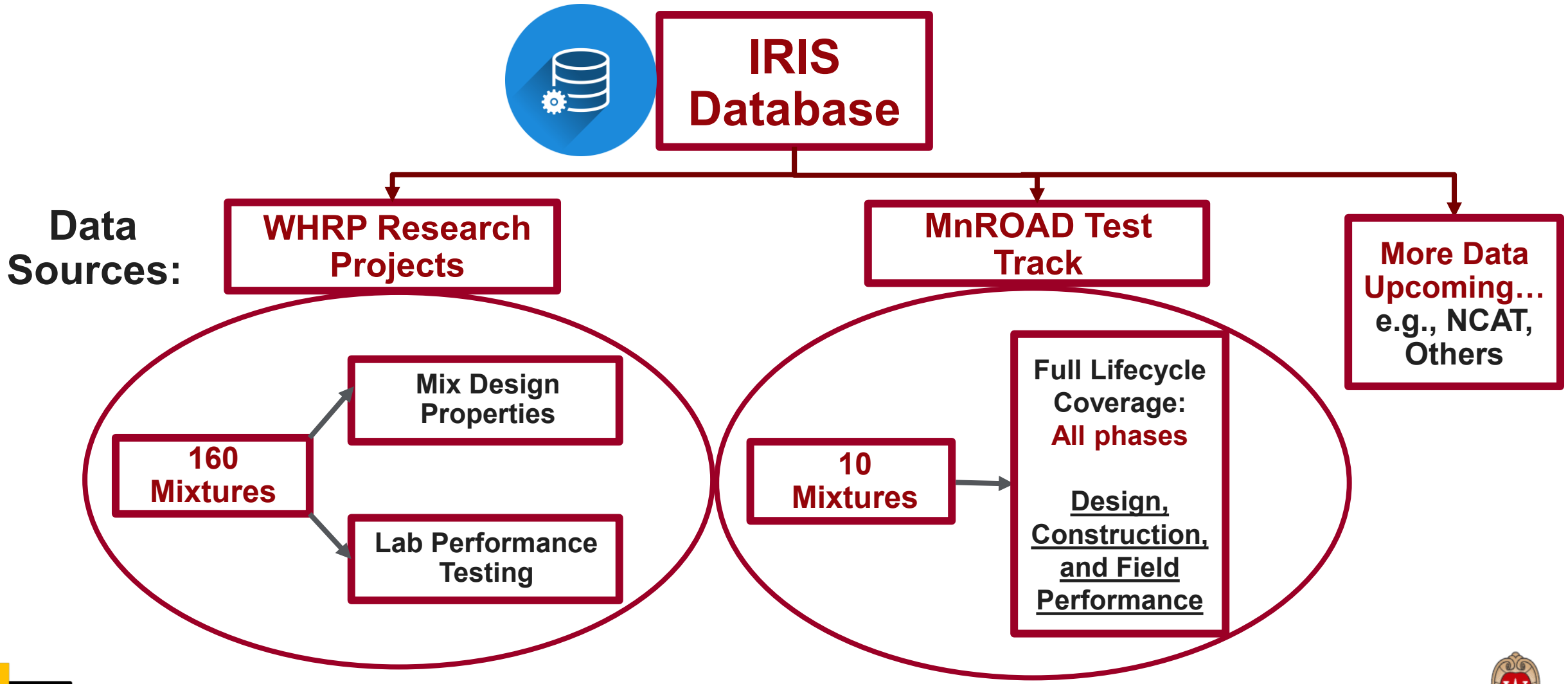
Climate & Traffic Data

Performance Data

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN-MADISON

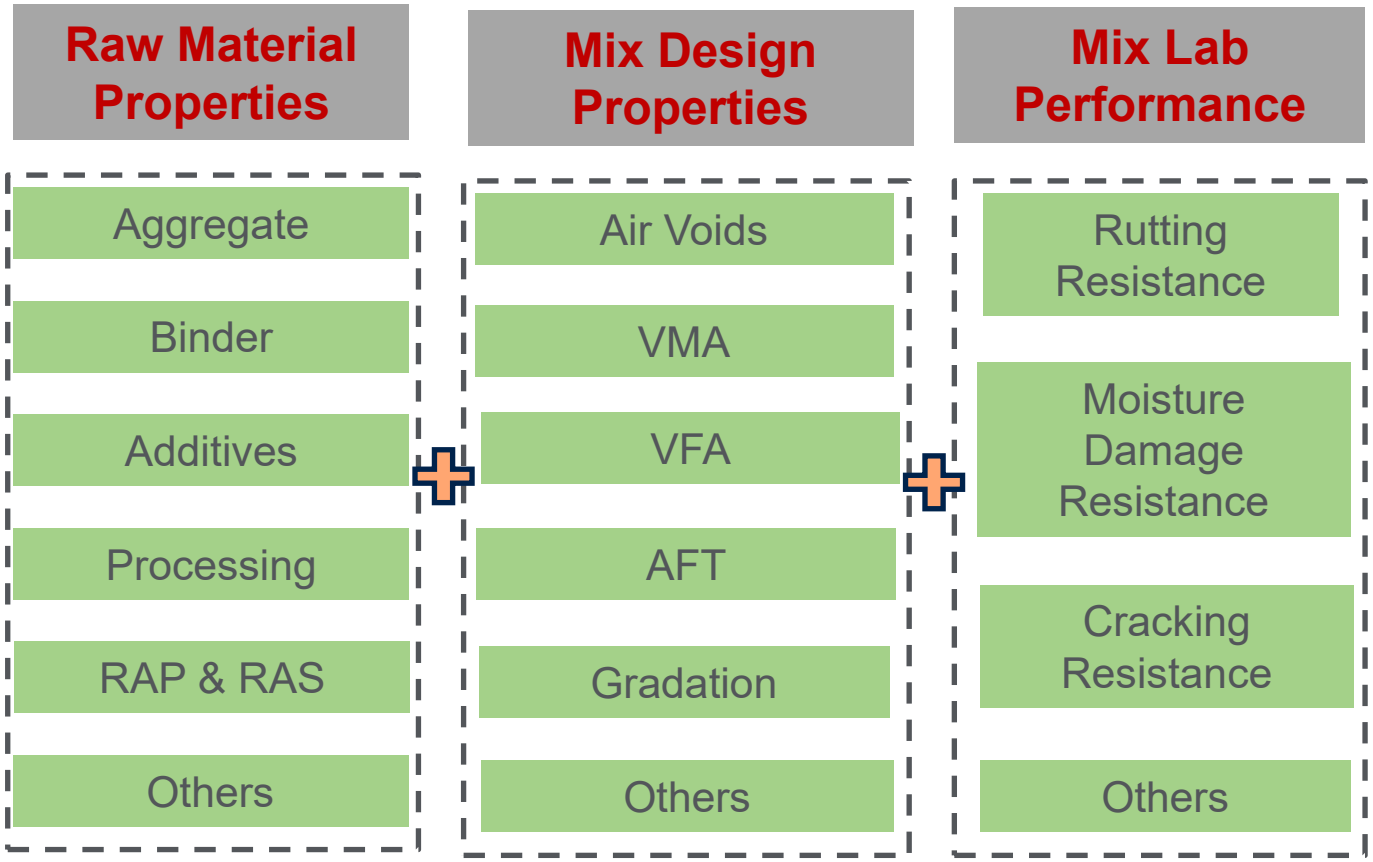
IRIS – Current (Preliminary) Database



SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

IRIS – Features of Existing Database



Various Data Attributes

Data Formats:

- Mix Design Report (MDR) / Job Mix Formula (JMF) - *PDF/Excel/CSV…*
- Volumetric Property Tables - *PDF/Excel/CSV/TXT…*
- Performance Test Results - *PDF/Excel/CSV…*
- Asphalt Binder Certificate of Analysis - *PDF/Excel/CSV/TXT…*
- Aggregate Properties and Consensus - *PDF/Excel/CSV/TXT…*

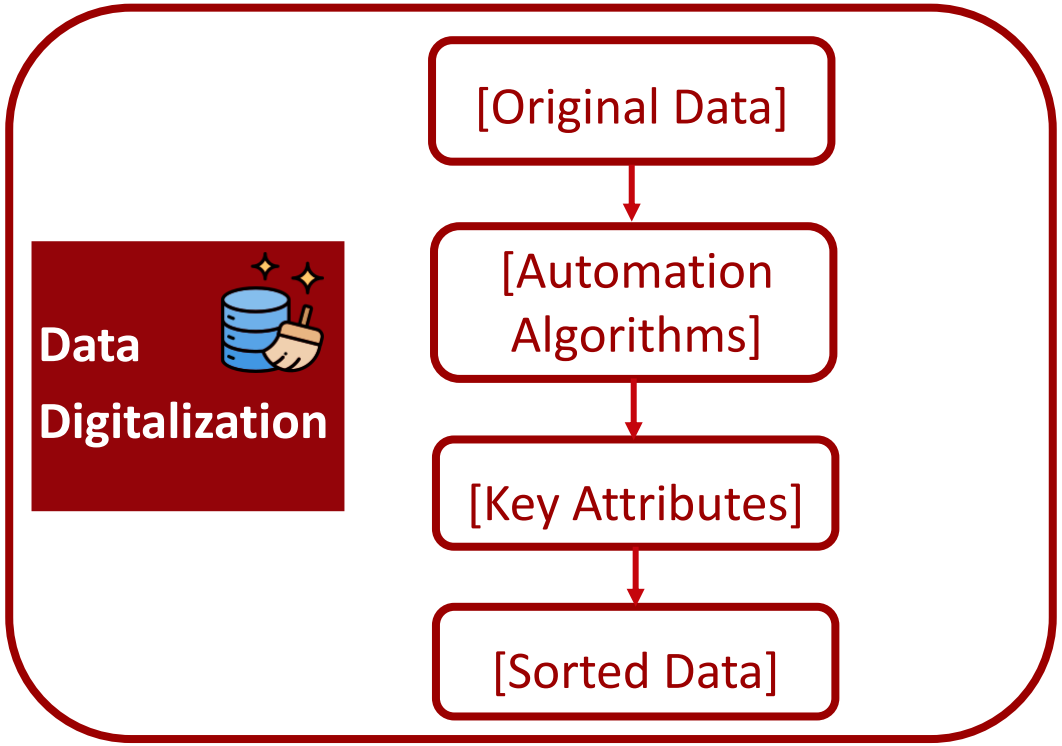
Miscellaneous Formats

SHRC SMART HIGHWAY RESEARCH CENTER

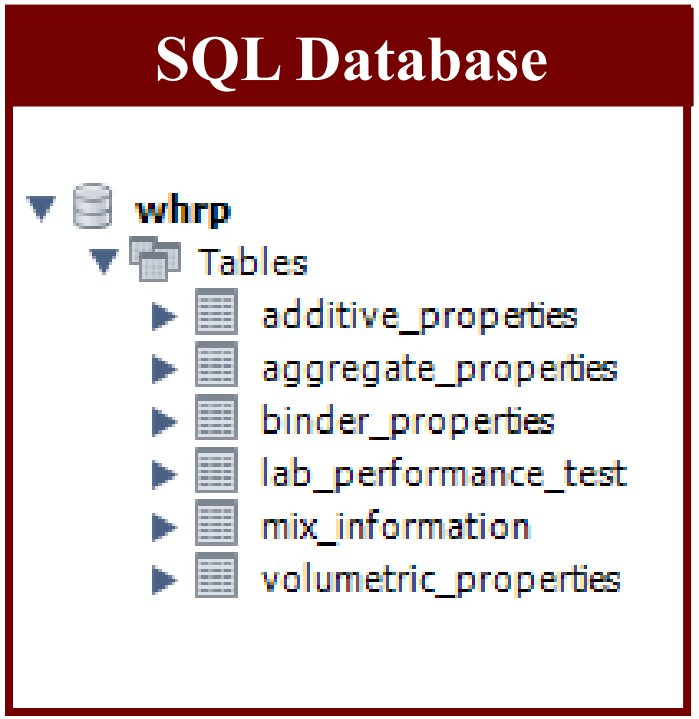
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

IRIS – Unified and Structured Database

Miscellaneous Data Formats



Unified Digital Database



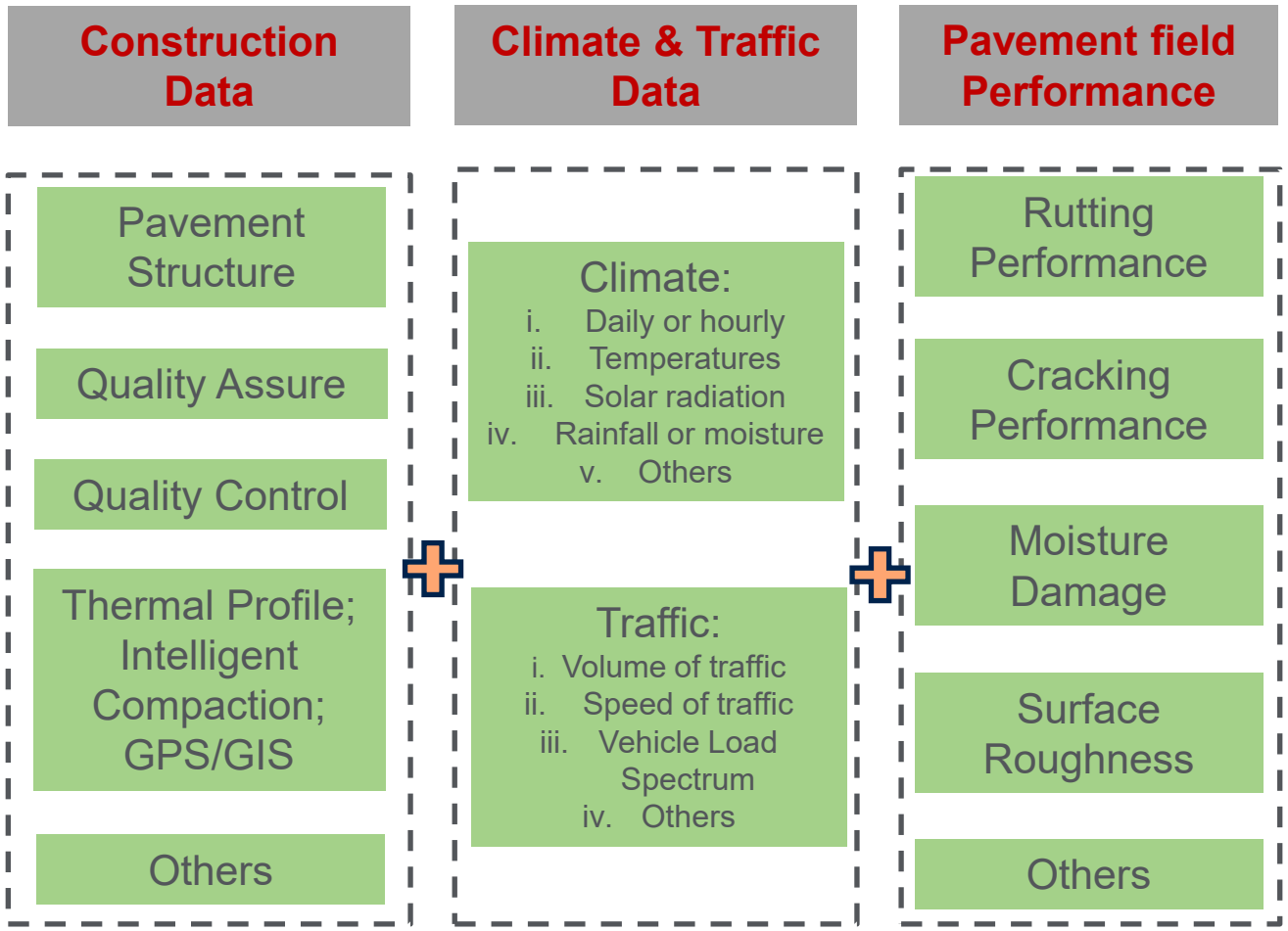
Ready for

- Analysis
- Modeling
- Visualization

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

IRIS – Features of Future Database



☐ Construction Phase:

- Asphalt Production Log （Excel / PDF）
- Delivery Tickets （PDF / JPG）
- Quality Control Test Results （Excel / CSV）
- Quality Assurance Test Results （Excel / PDF）
- Paving Logs （Excel / PDF）
- Field Core Test Reports （Excel / PDF）
- Others

☐ Service Phase:

- Ride Quality / IRI （Excel / Sensor Data）
- Distress Survey (Crack, Rut, Pothole) (PDF / Excel / GIS file / Video)
- Maintenance Records （Excel/PDF）
- Rehabilitated Section Info （Excel/PDF
- Climate & Traffic Records （Excel / CSV）
- Others

➢ **We need data from these phases**

SHRC SMART HIGHWAY RESEARCH CENTER

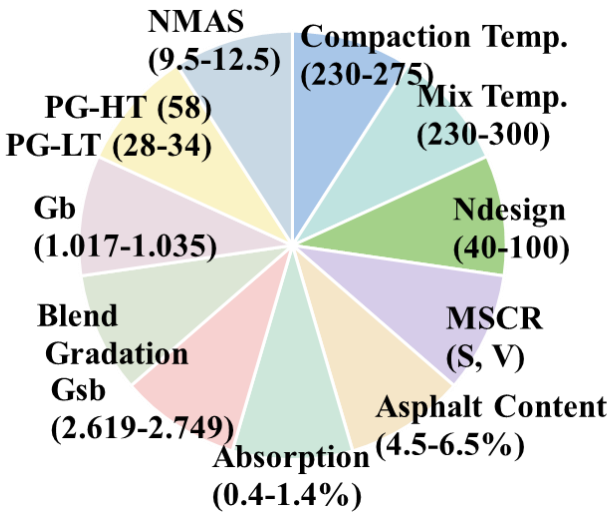
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

IRIS – Current Progress

Predict Asphalt Mix Design and Lab Performance Using AI

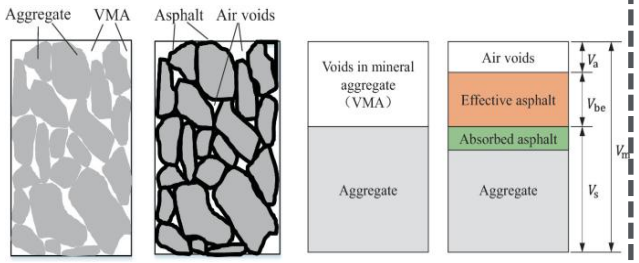
Input:

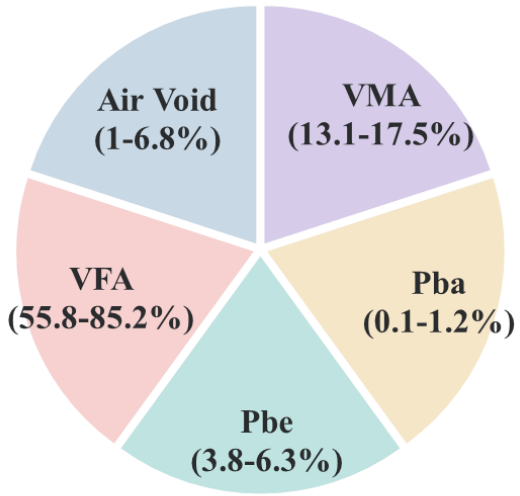
Raw Material Properties



First Level Output

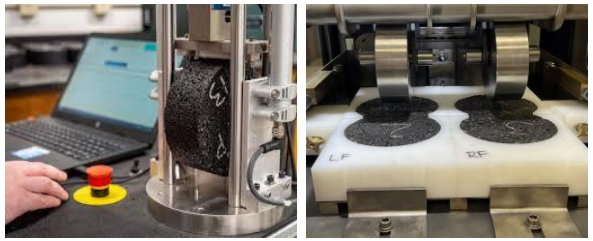
Mix Volumetrics

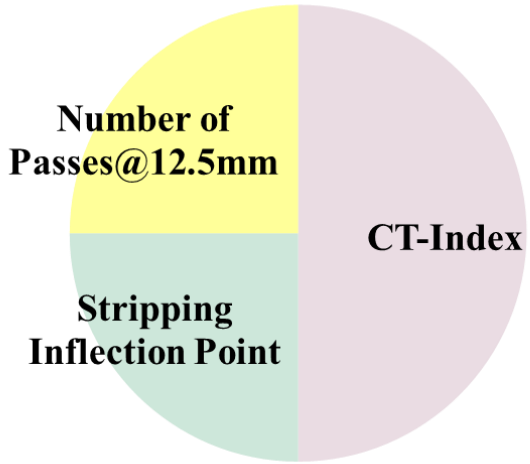




Second Level Output:

BMD Performance





CRD and SN are being calculated

SHRC SMART HIGHWAY RESEARCH CENTER

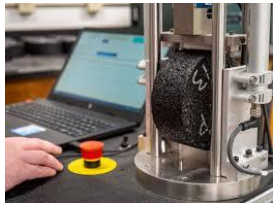
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

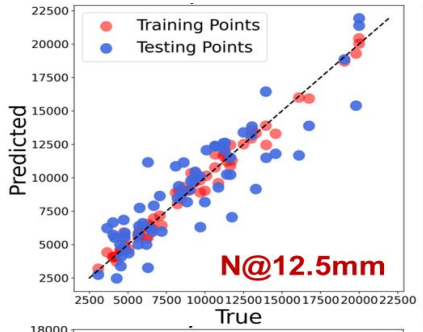
IRIS – Future Plan

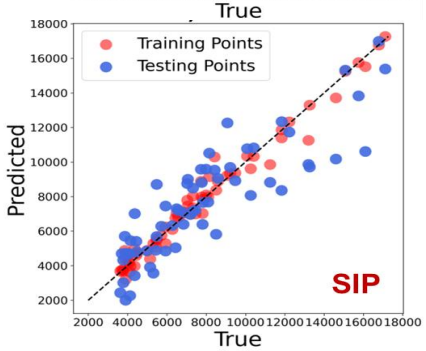
Predict Field Performance and Maintenance using AI

Input 1

Mix Lab Performance





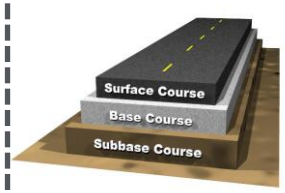


Selected Input 2:

Climate & Traffic Data

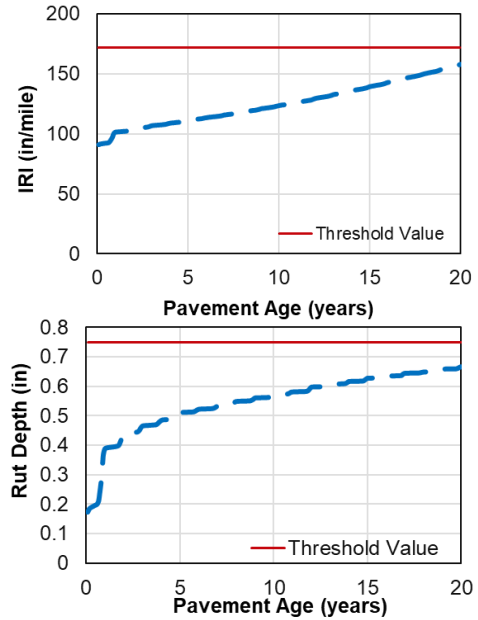
Selected Input 3:

Construction Data



Output:

Field Performance Data



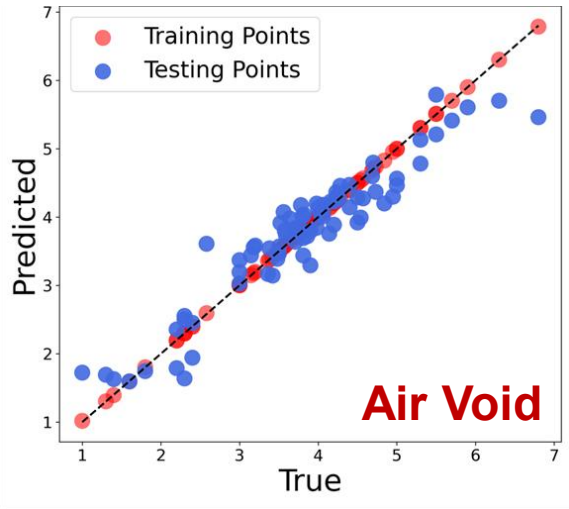
SHRC SMART HIGHWAY RESEARCH CENTER

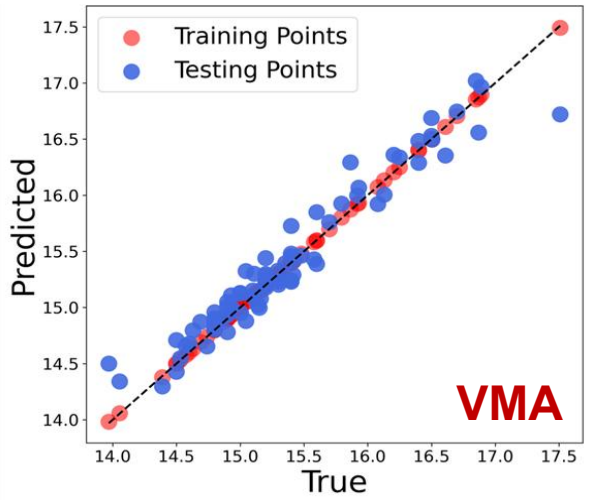
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

IRIS - Current Results

AI-aided Asphalt Mix Design – Volumetrics Prediction

- **Data Preparation**
  - Remove incomplete entries
  - Outlier detection (LOF + Z-score)
  - Variables correlation analysis: avoid overfitting
  - SHAP analysis: remove low-impact variables
- **AI Modelling**
  - Machine learning algorithms: MLP, XGBoost, Random Forest, RidgeCV





Target	Setting	Training R^2	Testing R^2	RMSE
Air void (%)	Original	0.879	0.625	0.614
	After Data Preparation	0.982	0.737	0.577
	Bailey Method+ Retained%+SHAP	**0.996**	**0.892**	**0.367**
VMA (%)	Original	0.822	0.596	0.531
	After Data Preparation	0.943	0.722	0.372
	Bailey Method+ Retained%+SHAP	**0.994**	**0.936**	**0.178**

Accuracy significantly Improved

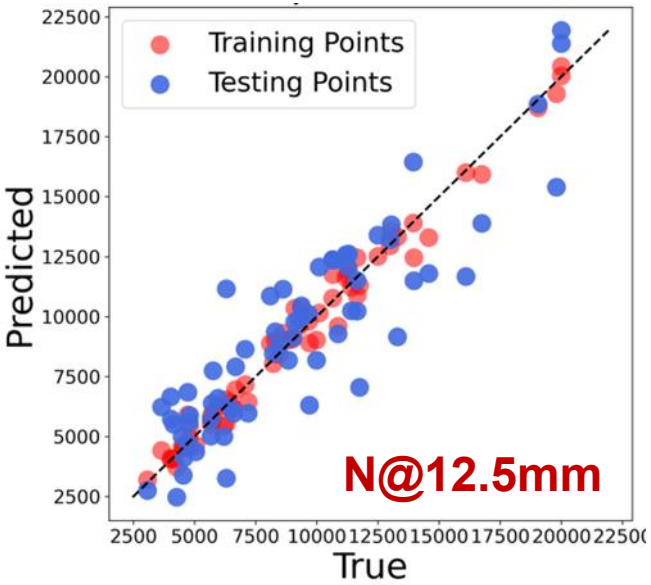
SHRC SMART HIGHWAY RESEARCH CENTER

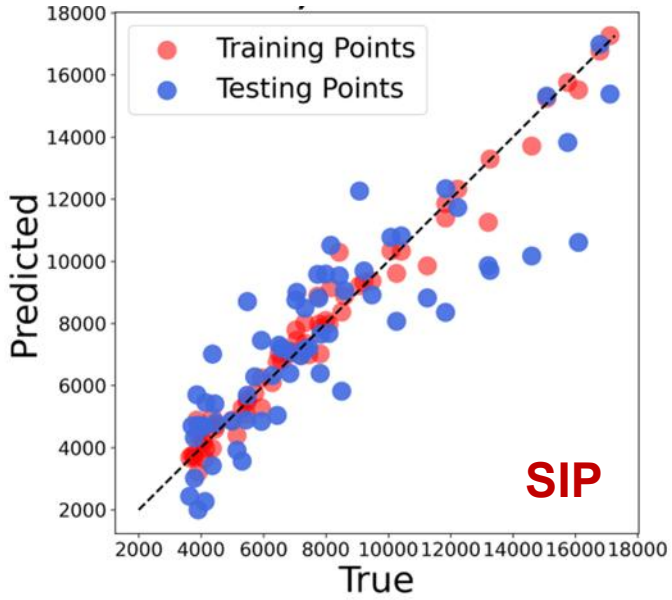
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

IRIS - Current Results

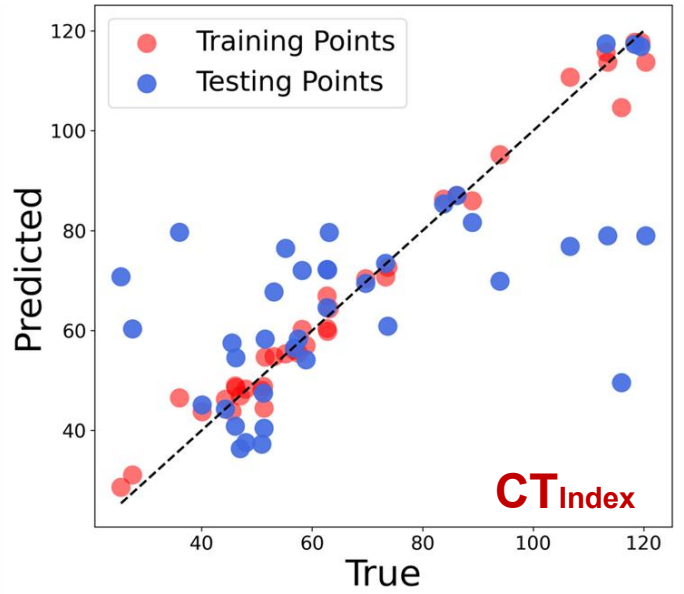
AI-aided Asphalt Mix Design – BMD Performance Prediction

Target	Setting	Testing R^2	RMSE
N@ 12.5mm	Original	0.628	2612
	Bailey Method+ Retained%+SHAP	**0.798**	**1943**
SIP	Original	0.513	2499
	Bailey Method+ Retained%+SHAP	**0.763**	**1745**





Target	Setting	Testing R^2	RMSE
CT-Index	Original	0.412	20.7
	Bailey Method+ Retained%+SHAP	**0.514**	**15.6**



Challenges:

- Limited amount of CT-Index data (~42 mixes)
- Tested on unaged or aged mixes

➢**We need more data for model improvement**

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

IRIS - Current Results

AI-aided Asphalt Mix Design – Prediction Models Validation

- **Five New Asphalt Mix Designs**
  - Not included in the AI testing and training dataset
  - MnDOT Surface Mix Design

Volumetrics

Mix Type	Air Void%	Predicted AV%	Residual AV%
SPWEC440	4	4.1	0.1
SPWEB440	4	3.8	-0.2
SPWEA440	4	3.7	-0.3
SPWEB340	4	4.1	0.1
SPWEB430	3	3.4	0.4

(<±0.5%)

Mix Type	VMA%	Predicted VMA%	Residual VMA%
SPWEC440	15.7	15.4	0.3
SPWEB440	15.5	15.4	0.1
SPWEA440	16.0	15.7	0.3
SPWEB340	14.9	15.0	-0.1
SPWEB430	14.7	14.9	-0.3

(<±0.5%)

BMD Performance (HWTT)

Mix Type	Measured N12.5	Predicted N12.5	% Error
SPWEC440	>20000	>20000	-
SPWEB440	19720	19537	0.93%
SPWEA440	20000	18750	6.25%
SPWEB340	14405	12981	9.88%
SPWEB430	20000	18270	8.65%

(<16.6%)

Mix Type	Measured SIP	Predicted SIP	% Error
SPWEC440	>20000	>20000	-
SPWEB440	19720	19537	0.93%
SPWEA440	20000	18751	6.25%
SPWEB340	14405	12981	9.88%
SPWEB430	20000	18270	8.65%

(<23.9%)

NCHRP 10-87, Precision Estimates of AASHTO T 324

SHRC SMART HIGHWAY RESEARCH CENTER

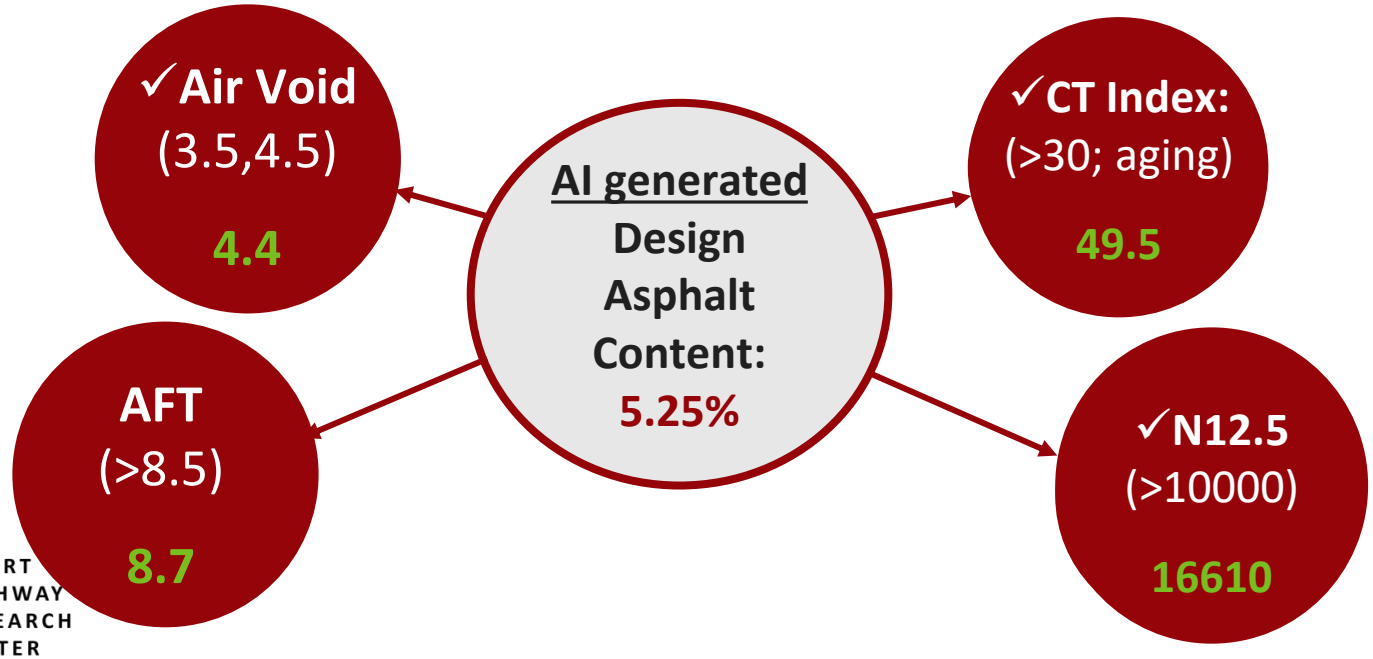
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

IRIS - Current Results

AI-aided Asphalt Mix Design – Mix Design Optimization

- Gradation and other properties are given
- Optimization Objective:
  - **Determine the asphalt content to meet both Volumetric and Performance Requirements**

Optimization Constraints / Performance Targets:



More Objectives/Targets Can Be Added:

Asphalt Properties;

Aggregate Properties;

Performance Criteria;

Environmental and Cost Aspects

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

IRIS – Example Benefits

Improvement in Design Efficiency

Current Practice

Trial Mix Design (iterative loop):

Traffic/climate → Binder selection (PG-grade, MSCR)

Traffic/climate → Trial gradations: 2–3 options

Target volumetrics & performance→ Trial binder contents: 3–4 options

Lab: Iterate until specs met: 6–12 tests (~3–4 h/test; ~24–48 h total)

Typical workload:
6–12 tests × ~3–4 h/test = ~24–48 h (~1 week)

AI-aided Mix Design

Workflow:

Traffic/climate → Binder selection (PG-grade, MSCR)

Target volumetrics & performance + traffic/climate → Optimal gradation: 1 option

Target volumetrics & performance → Optimal binder content: 1 option

Lab: 1 test to verify and fine-tune (~3–4 h)

Current workload:
1 test to verify = ~3–4 h

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

IRIS – Webtools (Expected in March 2026)

Implementation – Access and use of AI tools

SHRC Website: https://uwmarc.wisc.edu/IRIS-Volumetrics

Volumetrics Prediction

Reset | Run | Export

1. Input Parameters (General Mix Information)

2. Input Parameters (Asphalt Properties)

Parameter	Value
Binder PG (°C)	
MSCR Designation	
Others (G*, δ, Jnr, and R%...)	

3. Input Parameters (Aggregate Properties)

Parameter	Value
Bulk Specific Gravity	
Others (Absorption, Gradation...)	

Final Prediction Result:

Air Void (%)	
VMA (%)	
VFA (%)	
AFT (μm)	
Pbe (%)	

Volumetrics Optimization

Reset | Run | Export

1. Optimization Objective

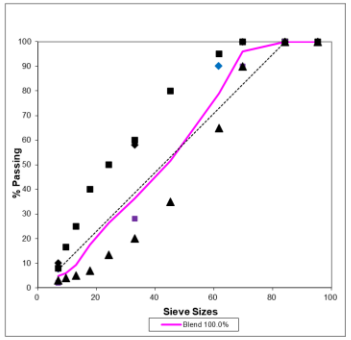
Parameter	Objective Chosen
Asphalt Binder Content (%)	☐
Aggregate Gradation	☑
Mixing Temperature (°F)	☐
Others (Ndesign, Compaction Temp.)	

2. Optimization Constraint and Target

Parameter	Target
Air Void (%)	
VMA (%)	
VFA (%)	
Others (AFT (μm), Pbe (%))	

Final Optimization Result:

Sieve Size	Value
25.0 (mm)	
19.0 (mm)	
12.5 (mm)	
9.5 (mm)	
4.75 (mm)	
Others	



SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

IRIS – Webtools (Expected in March 2026)

Implementation – Access and use of AI tools

SHRC Website: https://uwmarc.wisc.edu/IRIS-BMD Performance

Performance Prediction

Reset | Run | Export

1. Input Parameters (General Mix Information)

2. Input Parameters (Detailed Mix Design Properties)

Parameter	Value
Binder PG (℃)	
Asphalt Binder Content (%)	
Aggregate Gradation	
Others (Air Void, VMA, VFA, AFT, Absorption…)	

3. Input Parameters (Testing Conditions)

Parameter	Value
Testing Temperature (℃)	
Others (Short-Term/Long-Term Aging …)	

Final Prediction Result:

HWTT – N@12.5mm	
HWTT – Stripping Inflection Point	
HWTT – CRD@20k (mm)	
IDEAL-CT – CT-Index	
Others (Fracture Energy…)	

Performance Optimization

Reset | Run | Export

1. Optimization Objective

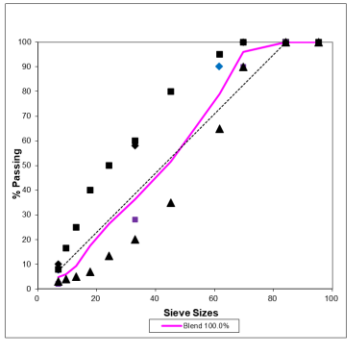
Parameter	Objective Chosen
Asphalt Binder Content (%)	☐
Aggregate Gradation	☒
RAP Content (%)	☐
Others (Asphalt PG, MSCR, Cost…)	

2. Optimization Constraint and Target

Parameter	Target
HWTT – N@12.5, CRD@20k (mm)	
HWTT – SIP, SN	
IDEAL-CT – CT-Index	
Others (Fracture Energy…)	

Final Optimization Result:

Sieve Size	Value
25.0 (mm)	
19.0 (mm)	
12.5 (mm)	
9.5 (mm)	
4.75 (mm)	
Others	



SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

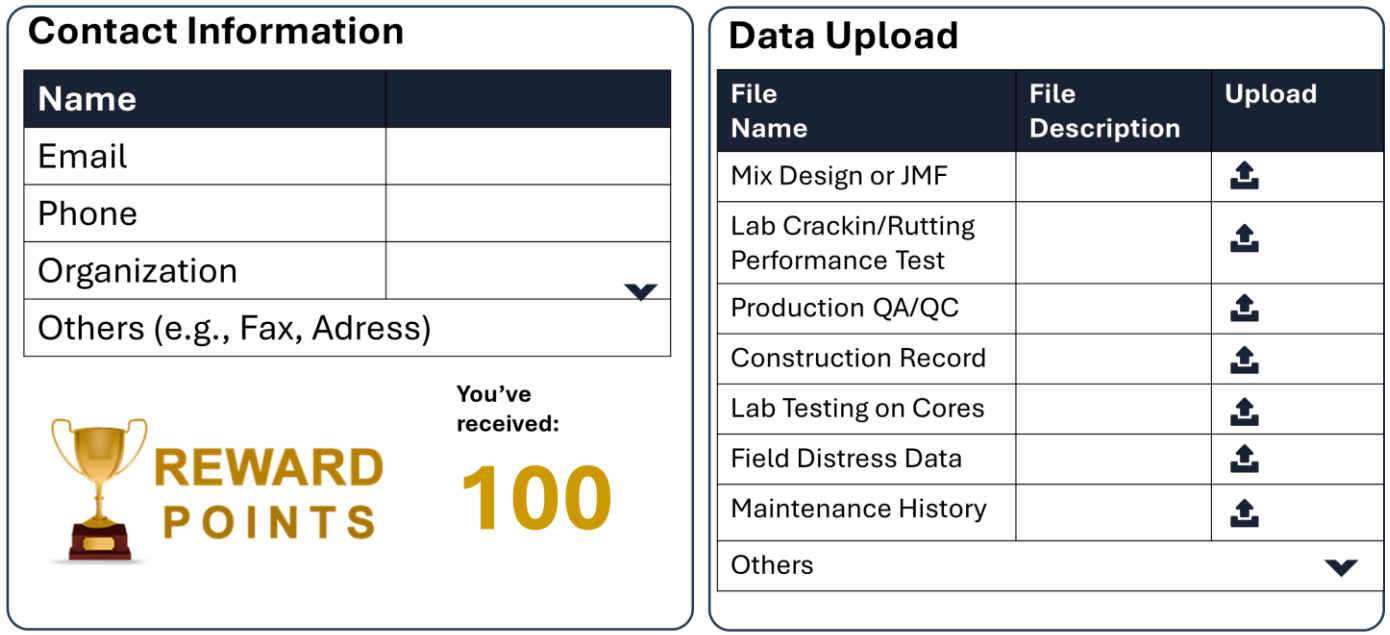
IRIS – Webtools (Expected in March 2026)

Data Upload and Reward Features

- Interface for data uploading will be developed:
  - Raw material properties/JMF
  - Performance testing results
  - Others
  - Keep data confidential
- Reward points for data sharing:
  - Free trials
  - License of tools

Please get in touch with us if you are interested in data sharing!

SHRC Website: https://uwmarc.wisc.edu/IRIS-Data Upload



Thank you for sharing the data!

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

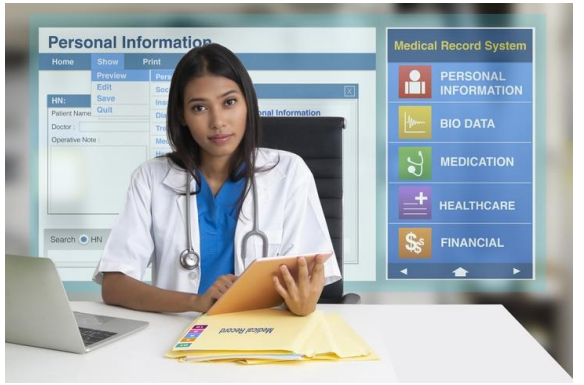
IRIS - Vision

Big Effort - Great Reward

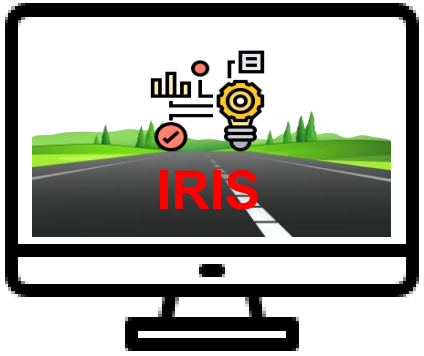
- **"Data is the oil, some say the gold, of the 21st century"**

  - Joe Kaeser, CEO of Siemens

Healthcare



Pavement



SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN-MADISON

Low-cost Pavement Condition Evaluation

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

Low-cost Roadway Condition Inspection

- **Current condition evaluation**:
  - Dedicated Inspection Vehicle
- **Challenges:**
  - Expensive Inspection Vehicle and Data Processing
  - Low inspection frequency
- **Solutions:**
  - Utilize a series of low-cost sensors and edge devices for inspecting road conditions
- **Benefits**
  - Cost-effective alternatives
  - More coverage and frequency

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON

Example - Pavement Condition Evaluation

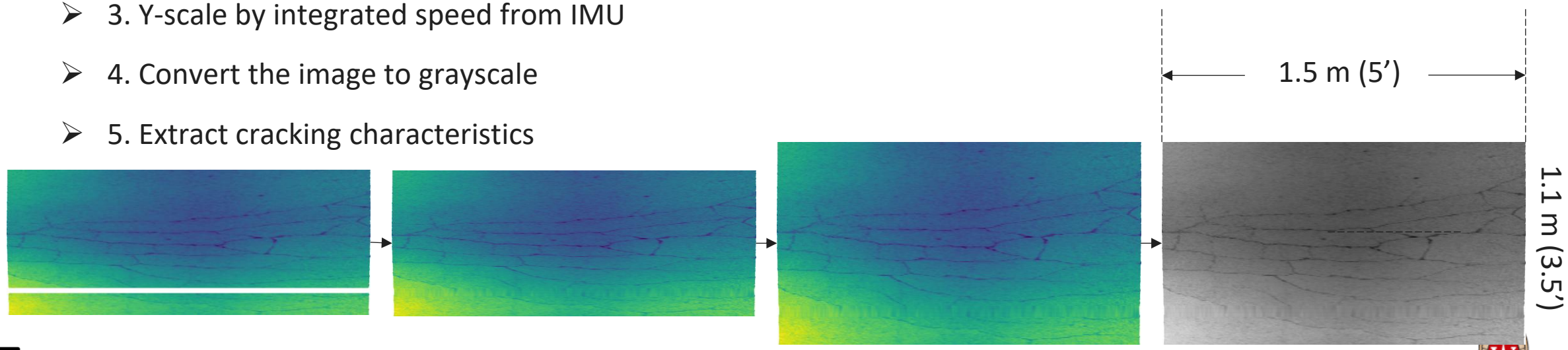
- **Project Background**:
  - HMA Overlay:
    - 2” overlay for 1 mile length
    - A trial project for an Iowa DOT research effort
  - Inspection before overlay
    - Requested by contractor
    - Reflective cracking study
- **System Setup:**
  - Laser beam mounted on research vehicle
    - Cost: <$10k
    - 3D surface profile – point cloud
  - GNSS system to record GPS coordinates

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

Example - Pavement Condition Evaluation

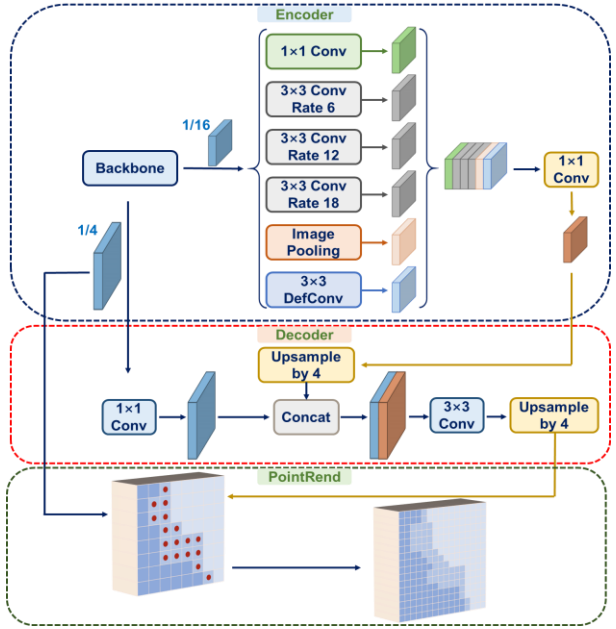
- **Data Collection and Processing Details:**
  - 5 runs on the two-lane road, 5 miles/hr.
  - Processing steps:
    - 1. Render BEV images from point cloud
    - 2. In-image repair (row fill, per-segment vertical fill, horizontal stretch)
    - 3. Y-scale by integrated speed from IMU
    - 4. Convert the image to grayscale
    - 5. Extract cracking characteristics

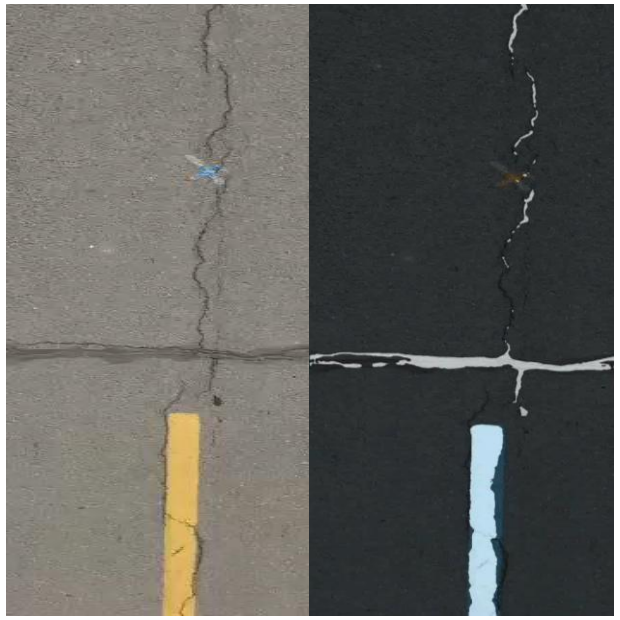


SHRC SMART HIGHWAY RESEARCH CENTER

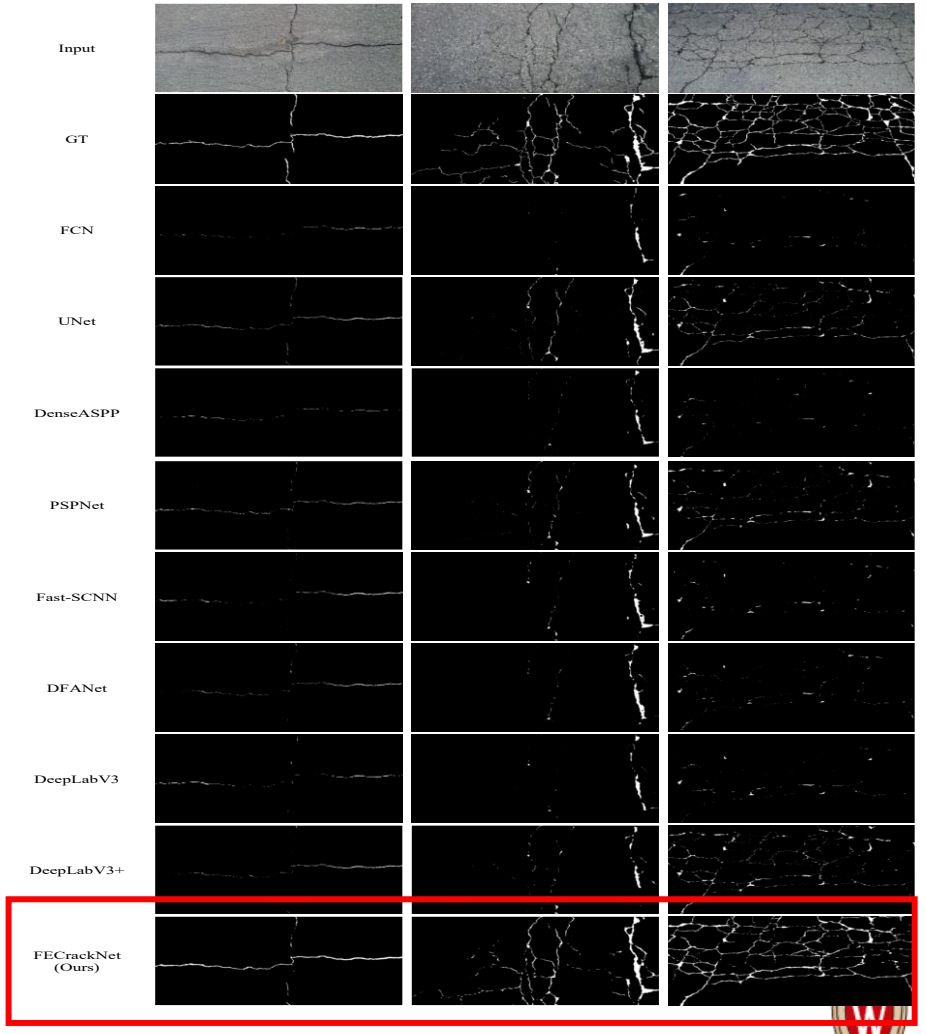
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

Cracking Characteristics Extraction





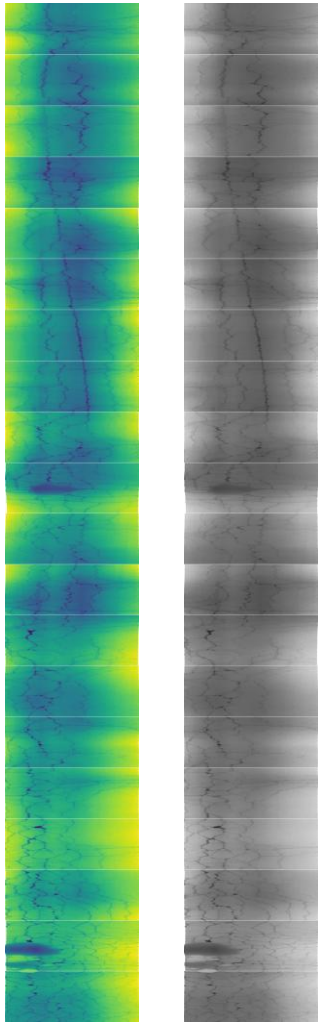
Model	Acc	Pre	Re	F1	mIoU
FCN	97.558	63.282	19.558	29.881	66.972
UNet	98.075	85.643	33.213	47.864	72.939
DenseASPP	97.597	80.552	12.753	22.020	67.809
PSPNet	98.165	86.976	36.464	51.386	75.356
Fast-SCNN	98.082	87.224	32.670	47.536	75.619
DFANet	97.832	86.844	21.809	34.863	70.468
FECrackNet	**98.398**	71.508	**66.108**	**68.702**	**75.803**

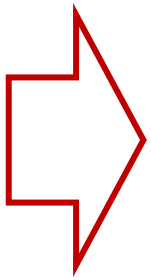


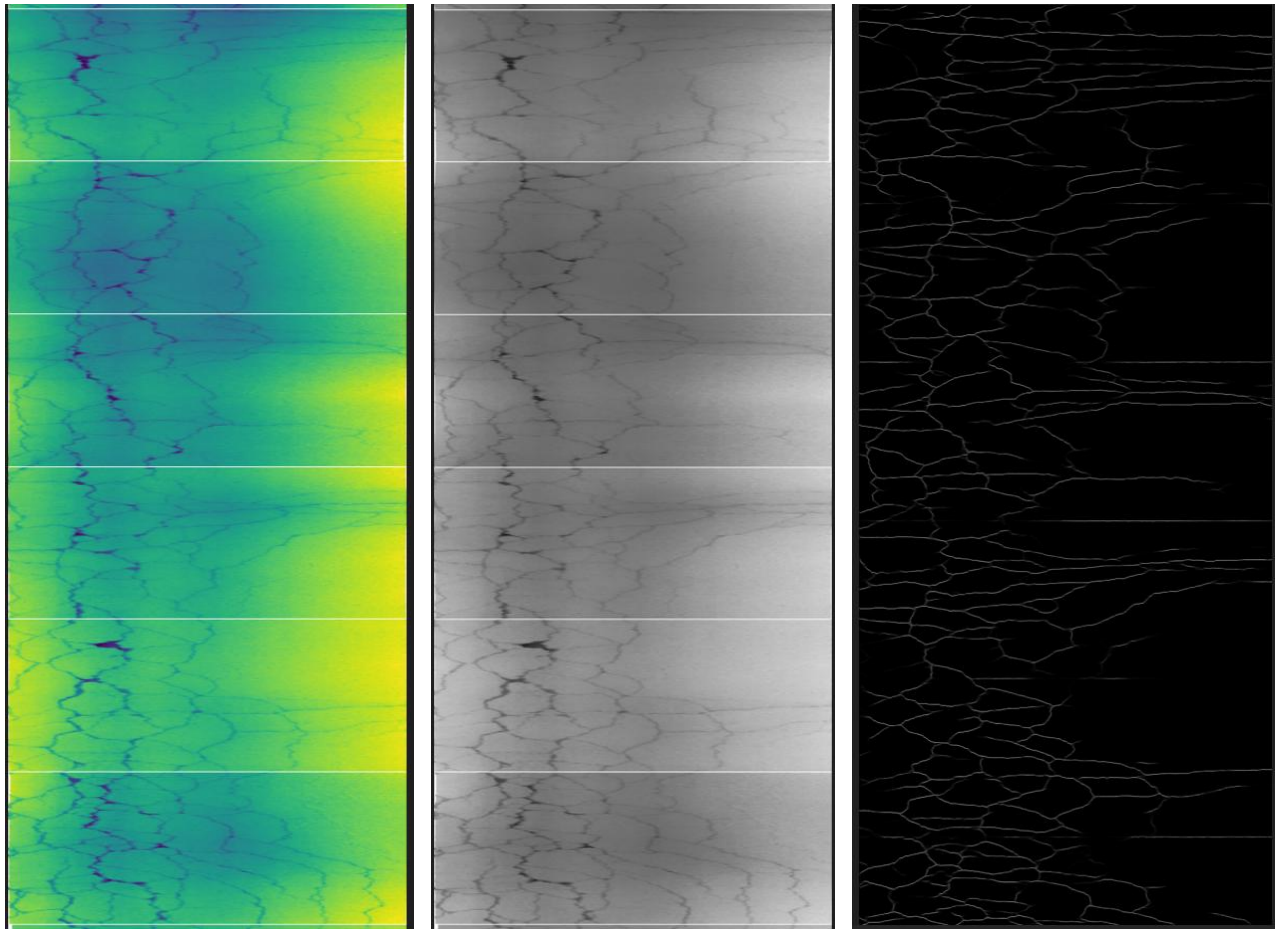
SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN-MADISON

Cracking Maps







crack_id	x	y	thickness_p
1	144	25	2
2	145	27	2
3	904	41	2
3	905	41	2
3	906	41	2
3	907	41	2
3	908	41	2
4	913	41	2
4	914	41	2
4	915	41	2
4	916	41	2
4	917	41	2
5	919	41	2
5	920	41	2
5	921	41	2
6	925	40	2
6	926	40	2
6	927	40	2
6	928	40	2
6	929	40	2
7	156	45	2
7	157	45	2
7	158	45	2
7	159	45	2
7	160	45	2
7	160	46	2
7	161	46	2
7	162	46	2
7	162	47	2
7	163	47	2
7	164	47	2
7	165	47	2
7	165	48	2
7	166	48	2
7	167	49	2
7	168	49	2
7	169	49	2
7	169	50	2

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

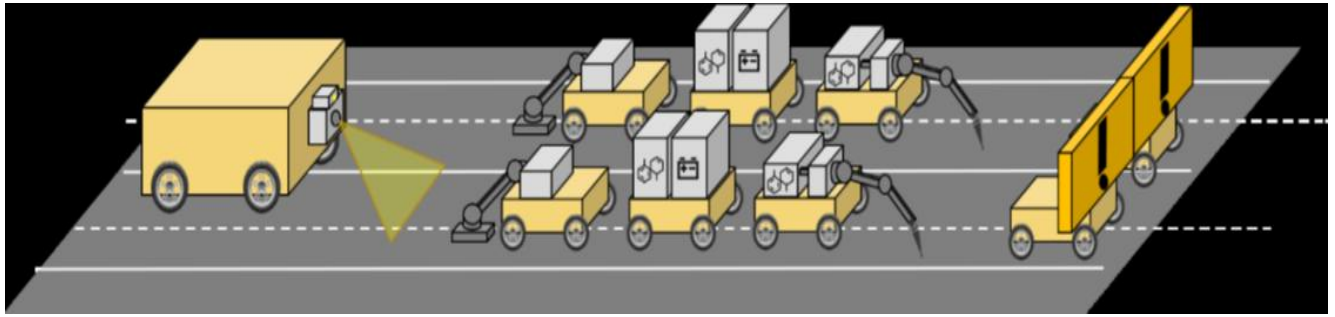
Modular Autonomous Road Maintenance System (MARS)

SHRC SMART HIGHWAY RESEARCH CENTER

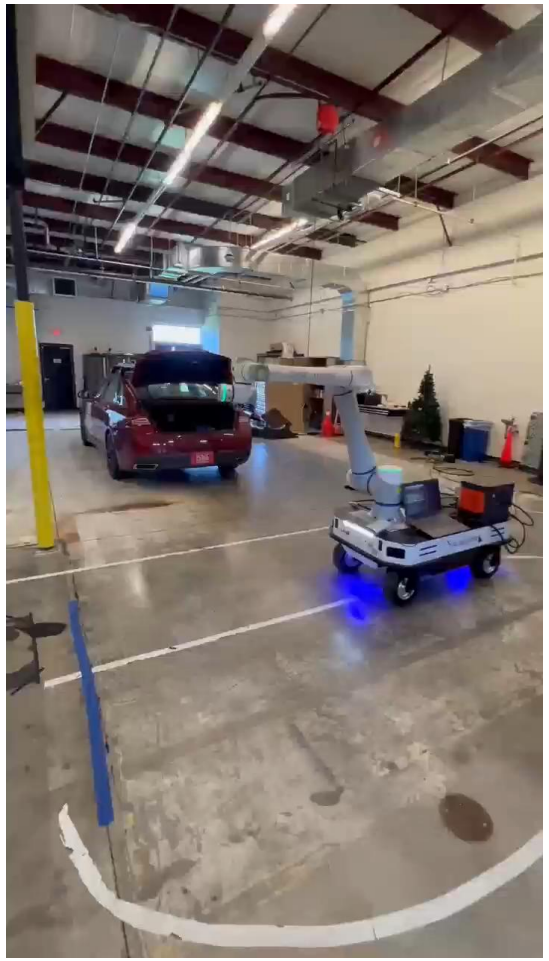
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

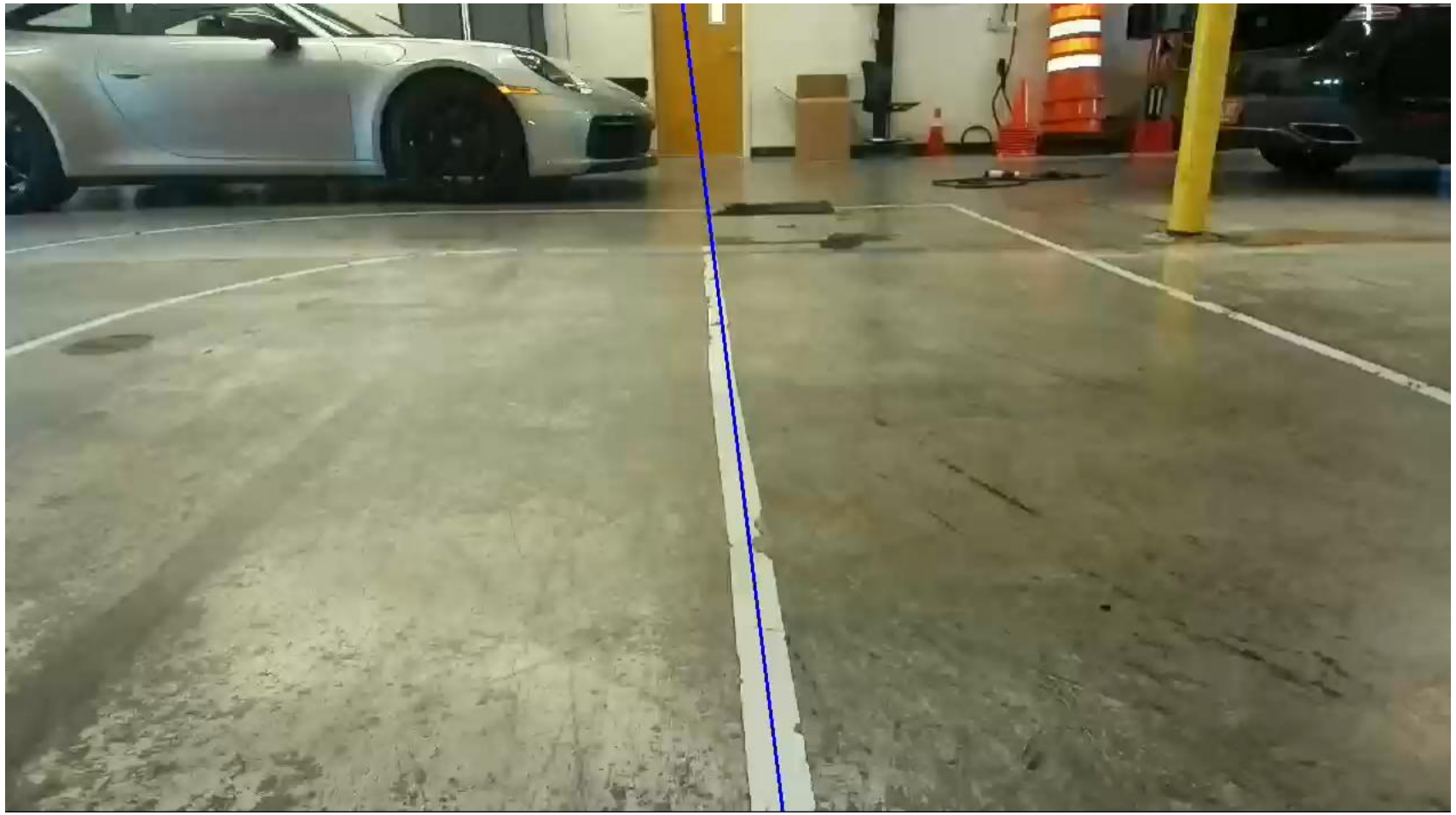
MARS
- Modular Autonomous Road Maintenance System (MARS)

- **Current maintenance**: Manually or construction vehicles
- **Challenges:**
  - Human labor intensive: limited efficiency; safety risks; labor shortage
  - Heavy-duty equipment
- **Solutions:**
  - Develop a Modular Autonomous Road Maintenance System (MARS) based on multiple small robots with specialized functions
- **Benefits**
  - Improve efficiency and safety



MARS
- Preliminary Result and Prototype





Summary

- **Development of Integrated Road Project Information System (IRIS)**
  - Utilize data and AI to assist in asphalt mix design
- **Low-cost Pavement Condition Evaluation**
  - More accessible and cost-effective alternatives
- **Modular Autonomous Road Maintenance System (MARS)**
  - Leverage AI, sensing, and autonomy for road maintenance

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

Collaboration Opportunities

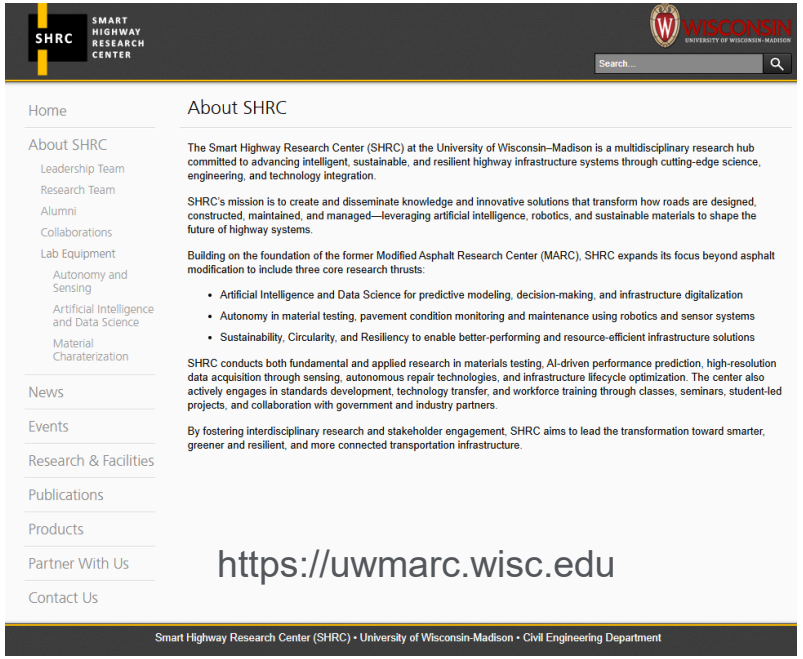
- **Data Sharing:**
  - IRIS development:
    - Design, construction, and service
    - Reward points
    - Non-disclosure agreement
- **Facilities Use:**
  - SHRC labs/equipment for service
    - Material testing
    - Low-cost inspection; sensors; robotics
- **Others:**
  - Customized projects
  - Commercialization/patent

SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

Acknowledgement

- **SHRC Leadership Team:**
  - Hussain Bahia, *hubahia@wisc.edu*
  - Xiaopeng (Shaw) Li, *xli2485@wisc.edu*
  - Sikai (Sky) Chen, *sikai.chen@wisc.edu*
- **Postdoctoral Researcher**
  - Gang Liu, *gliu244@wisc.edu*
- **Graduate Student**
  - Weiran Han, *whan72@wisc.edu*



SHRC SMART HIGHWAY RESEARCH CENTER

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

Thanks!

Runhua Zhang: runhua.zhang@wisc.edu
3352 Engineering Hall
1415 Engineering Drive, Madison, WI

Smart Highway Research Center (SHRC):
https://uwmarc.wisc.edu

Runhua Zhang, Hussain Bahia; Xiaopeng (Shaw) Li; Sikai (Sky) Chen
University of Wisconsin-Madison